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AUTOMATIC CONTROL OF AN ACTIVATED SLUDGE REACTOR

FINAL REPORT

FWQA GRANT # 17050 EVF

by

University of Connecticut

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Connecticut University, Storrs

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A feed forward control scheme was constructed and demonstrated on a pilot activated sludge reactor using as feed the primary effluent from a municipal treatment plant. The control scheme can be used to control both the air and recycle solids rates to the reactor to compensate for the increased carbon level in the feed stream. At normal detention times an improvement in process efficiency was observed with the control scheme.

*Activated sludge, *Automatic control, *Pilot plants, *Waste water treatment, *Control systems, Water pollution control, Treatment facilities, Effluents, Municipal wastes

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Introduction

Since there is an increased emphasis on water quality and the meeting of water quality standards by industrial and municipal groups, the analysis of waste water treatment plants by systems analysis techniques is becoming more common. A significant amount of the literature has been devoted recently to the modeling, simulating, optimizing, instrumentation, and controlling of water pollution processes and unit operations. The costs of waste water purification are being considered also beyond the individual treatment plant on a regional river basin basis. In such river systems it is important to be able to control the level of waste input to the river in spite of fluctuating demands on the individual treatment plants due to increases in flow and concentration of the waste in the sewage. The waste treatment plants should be designed with sufficient process control to be able to handle these changes. This report summarizes the work done on controlling the effluent water quality from an activated sludge reactor installed in the University of Connecticut sewage plant where the reactor is subjected to concentration changes.

Biological reactors, and activated sludge reactors in particular, are often difficult to control. Usually they are characterized by long residence times (1-8 hours), non-linear reaction kinetics, and undefined mixing. In addition, they are autocatalytic and often have mixed types of bacteria and substrates. From a process control view, the long residence time and undefined mixing are very important. If there is a change in waste concentration into the reactor it may be at least 1/4-1/2 a residence time before the change is significantly reflected in the output of the reactor. When the output is detected to exceed the limits of acceptability it may be difficult to bring the process in control again to discharge water of an acceptable quality. When the process sensor is at the discharge in the reactor, the process is in feedback control. When a long response time is present, it is necessary to implement feed forward control where the concentration sensor is shifted to the waste stream entering the reactor. Consequently, any corrective control action must now be based on some functional relationship, often a model, between the input concentration and the controller and not upon how well the reactor is

maintaining the discharge concentration within acceptable levels. If the activated sludge reactor and its controllers are simulated on a computer, there is little difference between the response of the reactor to feed forward or feed-back control. In practice, however, this may not be the case due to the experimental uncertainities in the automatic analysis equipment. During a simulation, the computer detects an error in the concentration to the eighth decimal place, while in practice changes of ±10% often lie within the error of analysis. For biological processes it is important to detect a change in the process as soon as possible by measuring input properties and not to wait until the change is transmitted to the output stream.

Equipment

A. Process and Equipment

The activated sludge system used in this study is shown in the flowsheet of Figure 1. The reactor, which holds 60 gallons of liquid, is shown in Figure 2, and is the same one described in more detail in earlier reports. The reactor pressure was controlled at 2.5 psig to give sufficient head to transport the discharge through the bottom control valve and into the settler. The settler consists of a 1.5 ft. diameter cylindrical midsection with a conical base, the combined volume being 55 gallons. The settled solids leave the bottom of the settler by hydrostatic head through a gate valve and are stored in a 55 gallon stainless steel drum with mixing until needed for recycle into the reactor. The feed and sludge recycle pumps are Milton Roy diaphragm pumps with 0-85 gph adjustable capacity. The recycle pump is equipped with a pneumatic positioner to allow the pumping rate to be proportional to a 3-15 psig air signal.

The waste water fed to the reactor was continuously drawn from the effluent of the primary settlers at the University of Connecticut treatment plant. Samples were t aken every hour of the settler overflow, the recycle sludge stream, the feed stream, and the reactor effluent. These samples were analyzed for total carbon and

total solids. The feed stream to the reactor was analyzed for total carbon concentration automatically every four minutes.

Control System Details

The feed forward control system is outlined schematically in Figure 1 and pictorially in Figure 3. A sample of feed water is continuously fed to a small centrifuge where all solids are removed. The filtrate is stored in a 20 cc graduate from which the Total Carbon Analyzer (TCA) aspirates a sample every four minutes. The 20 cc graduate provides enough reservoir for the aspirator and any excess filtrate beyond the 20 cc is discarded. Liquid is aspirated for about 10 seconds from the graduate, during which time 40 microliters of it is injected into the combustion chamber gas stream. The gas stream from the TCA is fed to an infrared analyzer sensitized for CO_2 detection. The height of the CO_2 peak from the infrared analyzer is proportional to the level of carbon in the feed water. The m.v. signal from the I.R. is sent to a recorder which is equipped with a retransmitting slide wire. The retransmitting slide wire is necessary to prevent the peak follower from being activated by spurious signals from the I.R. sensor. Several means were tried without success to electronically suppress the extraneous noise when the I.R. sensor was connected directly to the peak follower. However, it was found that with the retransmitting slide wire the recorder acts as a perfect noise filter and no false peaks were sensed. The 10 m.v. signal from the retransmitting slide wire is sent to the peak follower which produces a step signal proportional to the peak heights of the entering signal. The peak follower, consisting of several track and hold circuits, was developed in conjunction with Neill Engineering Company. The millivolt output from the peak follower is sent to a converter which changes the signal to 3-15 psig. This pneumatic signal is used directly to change the flow rate of return sludge by activating a positioner on the recycle sludge pump. As mentioned earlier, with feed forward control, the control action (rate of return

sludge) must be coupled through some functional relationship to the feed concentration. In this case, a linear relationship has been used, although a non-linear function generator using Monod kinetics would have been a more realistic model. The recycle rate, under control, was determined from the following:

$$R = \frac{R_{ss}}{100} \times C$$

where R = recycle rate, gph

R_{ss} = steady state recycle rate for comparison, gph

C = concentration of carbon in feed stream, mg/liter

F = rate of fresh feed into reactor, gph

V = volume of reactor, gallons

= 60 gallons

$$1 \leq F/R_{ss} \leq 4$$

$$1 \text{ hr} \leq V/F \leq 4 \text{ hours}$$

This recycle relation is introduced into the control loop by adjusting the zero and span settings on the Foxboro pneumatic converter and on the pneumatic positioner on the pump.

When the carbon level into the reactor is 100 mg/liter, the recycle feed rate is equal to that of the run on the previous day where the recycle rate was held at a constant value. A steady state run and a control run were made on two consecutive days to minimize differences in recycle sludge concentration and sludge activity. This relationship between the recycle sludge and the feed concentration was arbitrarily chosen. In the field, it would be tuned to the particular process and plant on which it is applied. Since the goal of this study was to demonstrate such a control scheme, the effort was spent on showing that the efficiency could be increased by automatically adjusting the recycle sludge rate rather than on arriving at those conditions for optimal control.

The output of the TCA and peak follower operating on primary effluent for a typical 10 hour period is shown in Figure 4. The recorder plot for the peak follower is placed on top of the TCA plot for comparison. The peak follower plot clearly shows several maxima in the feed concentration during this period. The square wave pattern on the peak follower curve gives an estimate of the uncertainty in the TCA analysis due to the presence of suspended and colloidal particles in the water. If pure organic compounds are dissolved in distilled water, the peak heights are reproducible. Periodically there is an unusually high peak which distortes the curve but does not cause any difficulty in control due to the short duration between samples. The small peaks between the large carbon peaks are from the injection of 100 microliters of distilled water into the combustion tube to purge out any remaining traces of the previous sample. In order to prevent the peak follower from lockin g onto the small distilled water peaks, the peak follower has an adjustable threshold above which the peak must rise in order for it to be sensed. The only difficulty experienced in the field by this control system was the infrequent locking of the peak follower on a noise signal caused by the shutting down of some large pump in the sewage plant. Whenever this malfunction should occur, it would be manually reset to the previous control setting. Unfortunately, the power and signal wires were not shielded and hence were subject to stray signals. This small problem in no way affected the satisfactory performance of this control system.

Results

In order to make a meaningful comparison between controlled and uncontrolled runs the runs should be made as close as possible, and the carbon concentration profiles in the feed stream (which can not be controlled) should be as similar as possible. Results are presented for both one and three hour nominal reactor residence times in order to view the control effectiveness at two levels of

conversion. The nominal residence time, θ, is defined as V/F and is not the true reactor residence time since the true flow rate is the sum of the fresh and recycle rates. When the recycle rate is changing in the controlled runs, the true residence time is also changing although V/F remains constant. The carbon response and the conversion for θ = 3 hours is shown in Figures 5 and 6. The fractional conversion is defined as the $\frac{\text{carbon in-carbon out}}{\text{carbon in}}$. At θ = 3 hours, the conversion is about 50% of the carbon (> 80% BOD) and is near that for municipal activated sludge reactors. In Figure 5, the carbon level out of the reactor is almost always lower under control than under non-control in spite of the higher carbon level in the feed during the control run. The fractional conversion for the uncontrolled run is always greater for control than for non-control. The total carbon and total solids analysis in all streams for θ = 3 hours are shown in Figures 9 - 12. It is important to note that the controlled run could maintain the high conversions in spite of increased carbon in the feed during the latter part of the run. The amount of improvement under control is not great primarily because at high conversions there is small room for improvement.

In order to see the effect of control more clearly, several runs were made with θ = 1 hour where the conversions would be lower. Unfortunately at the higher flow rates necessary to give θ = 1 hour, the settler efficiency declined to the point where sludge wastage from the settler become important enough to make our recycle solids concentration lower during the controlled than during the uncontrolled runs. Since the flow rate of recycled solids is greater in controlled runs, the net effect was to have the concentration of solids in the reactor about the same. In Figures 7 and 8 are the reactor feed and exit carbon levels as well as the conversions for control and no-control runs. The total carbon and total solids analysis on all streams for θ = 1 hour are shown in Figures 13-16. The carbon effluent concentration is higher in the control run than in the no-control run

during the first third of the run, and equal to it during the remaining 2/3 of the run. This outcome is to be expected when the input carbon is < 100 ppm, since the recycle sludge rate for control is < that for no-control giving a lower sludge concentration in the reactor. In the later part of the run the solids concentration increases to that for no-control due to increased recycle and the two effluent concentrations become equal. The same performance is seen on Figure 8 where the conversion for control is < that for no-control during the first part and they are approximately equal during the later part. Therefore, the results for $\theta = 1$ are inconclusive in predicting better performance under control, due to the inability of the settler to build up a high concentration of recycle solids. Future tests will be made at $\theta = 1$ by using a smaller volume in the reactor and a smaller feed rate. By cutting both the volume of the reactor and the feed rate of 1/3 of the present levels, θ will remain equal to one but the duty on the settler will be only 1/3 as much and hence its efficiency will be restored.

Conclusions

1. A feed forward control scheme was constructed and demonstrated on a pilot activated sludge reactor using as feed the primary effluent from a municipal treatment plant. The control scheme can be used to control both the air and recycle solids rates to the reactor to compensate for the increased carbon level in the feed stream.
2. When the pilot reactor was operated at conversion and residence times characteristics of minicipal plants, the conversion was increased when the return rate of recycle solids was controlled as a function of the input carbon level.
3. When the pilot reactor was operated at lower conversions and lower residence times the results were inconclusive. The dynamics of the settler become controlling and the concentration of recycle solids was not adequate to improve the performance.

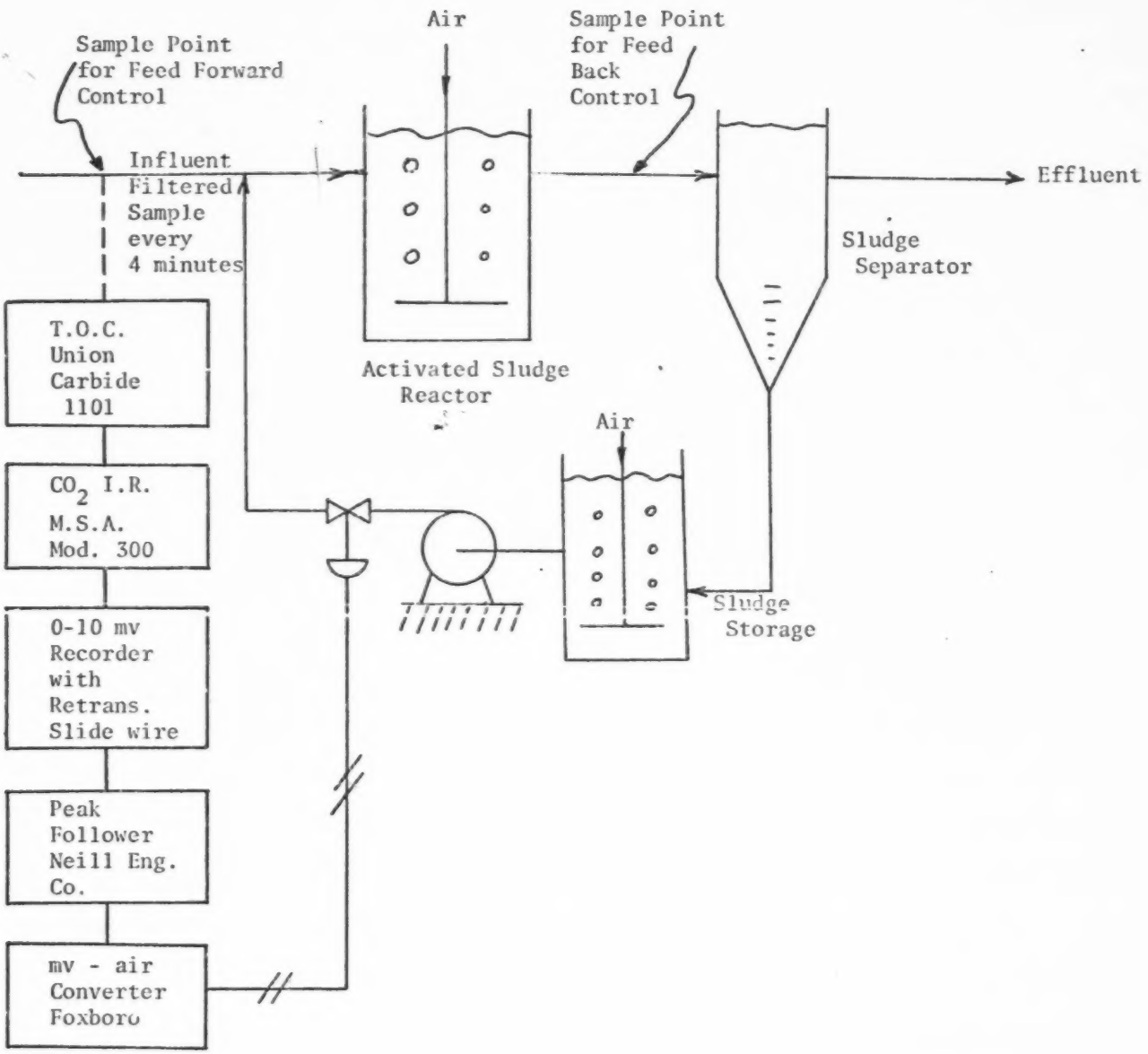

FIGURE 1.

Control System on U-Connecticut Pilot Activated Sludge Reactor

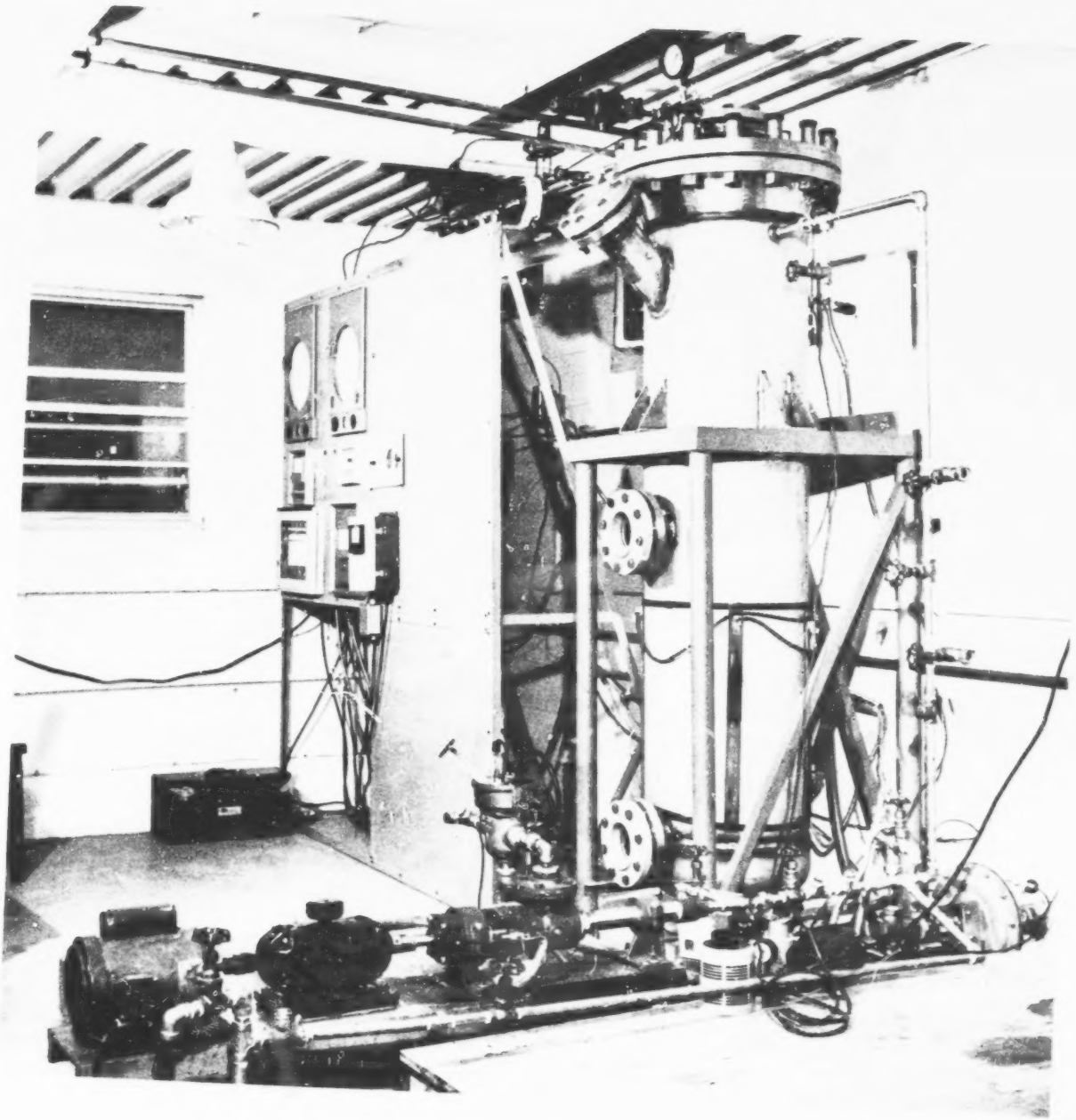

Figure 2

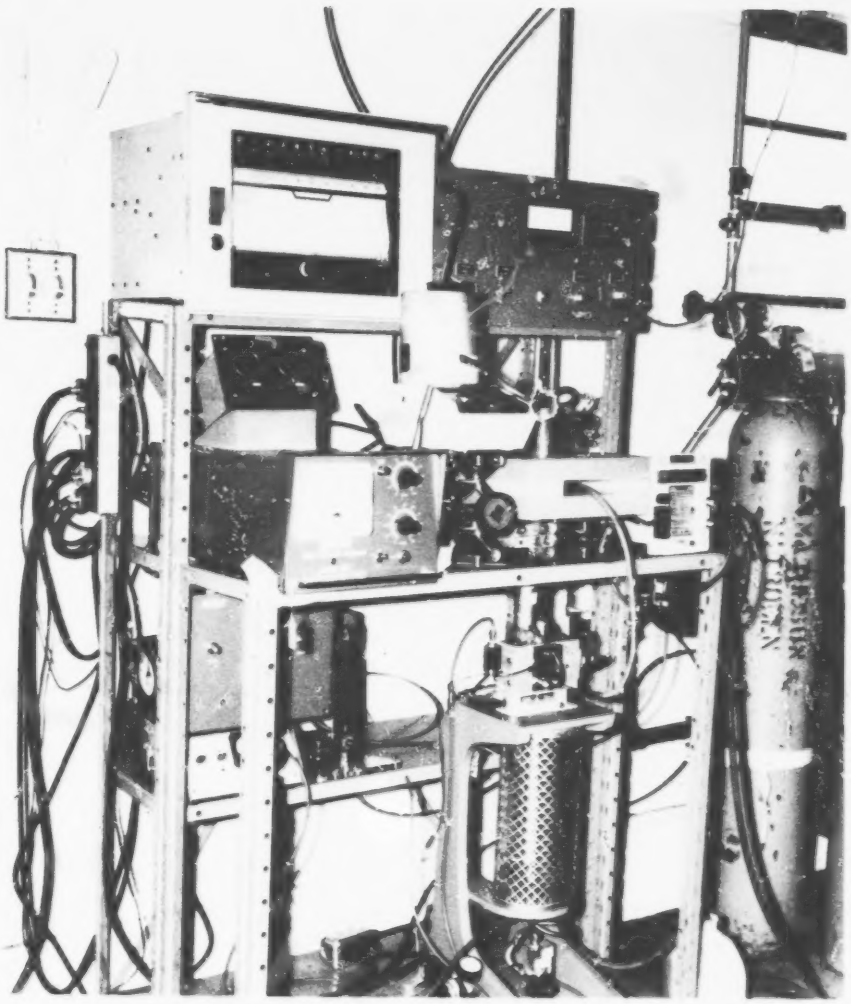

Figure 3

Feed Forward Control Instrumentation

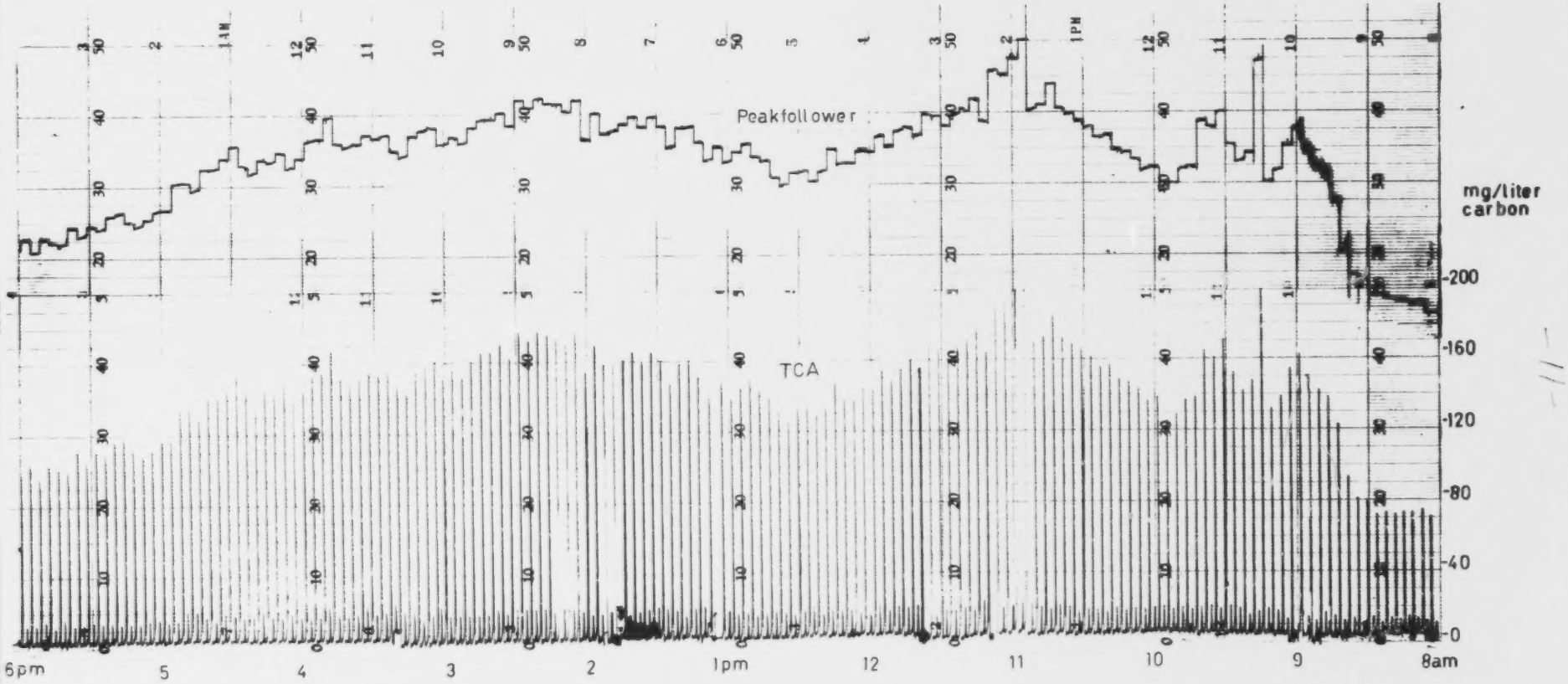

Figure 4

Output of Peakfollower and TCA on Primary Effluent for One Day

K&E 10 X 10 TO THE CENTIMETER 46 1510
10 X 25 CM.
KEUFFEL & ESSER CO.
MADE IN U.S.A.

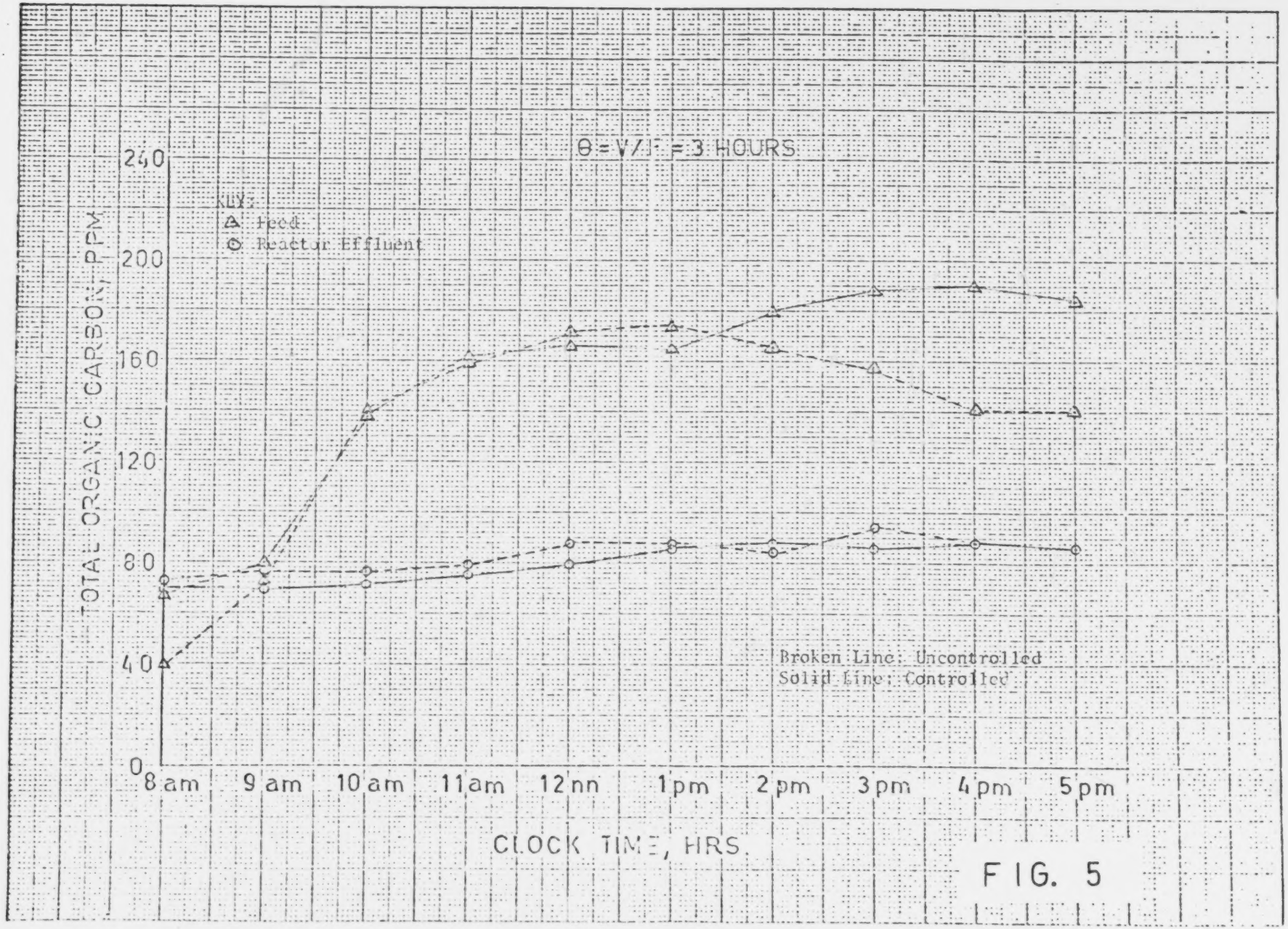

FIG. 5

KE 10 X 10 TO THE CENTIMETER 4G 1510
10 X 25 CM.
KEUFFEL & ESSER CO.

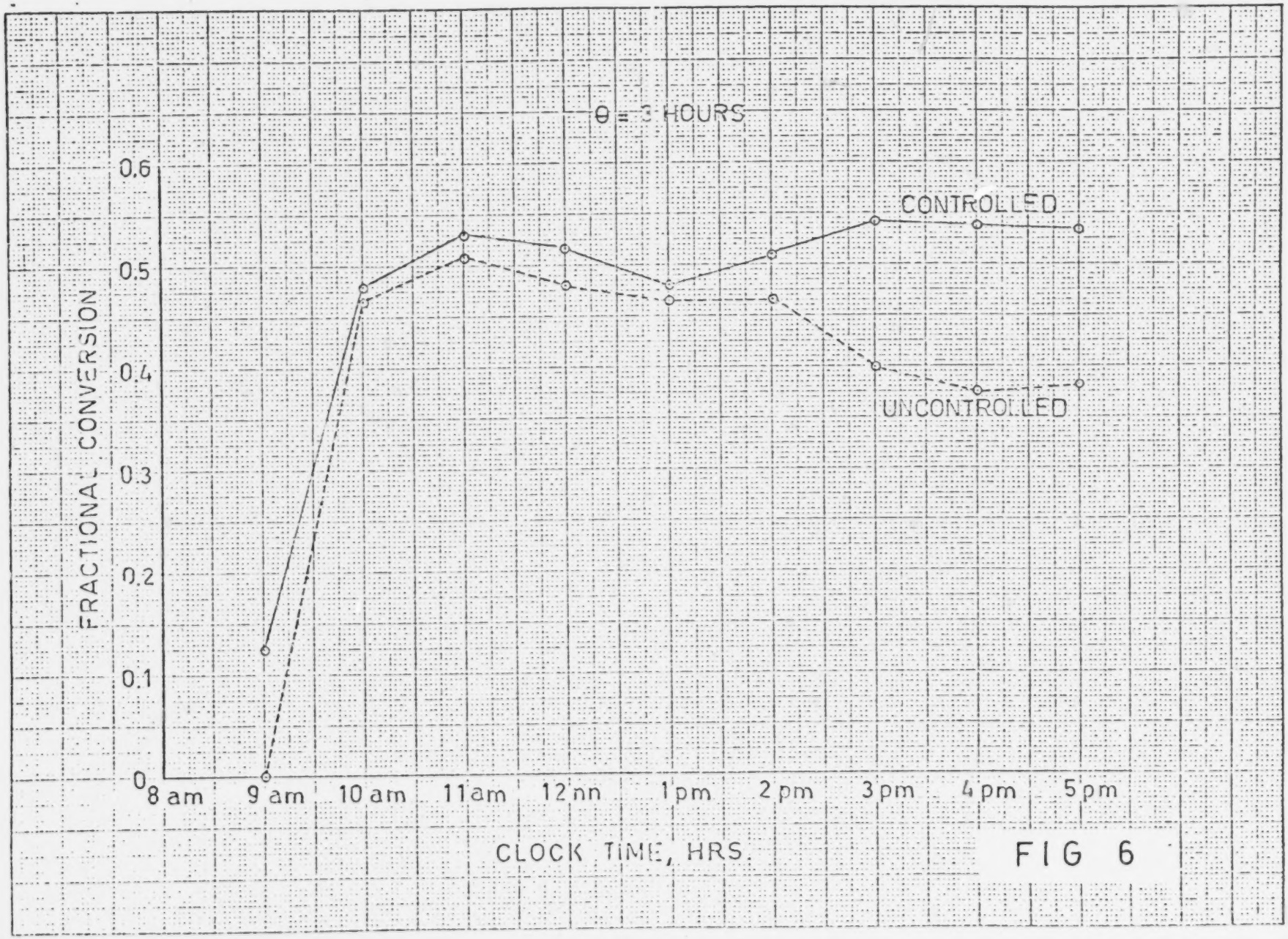

FIG 6

18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

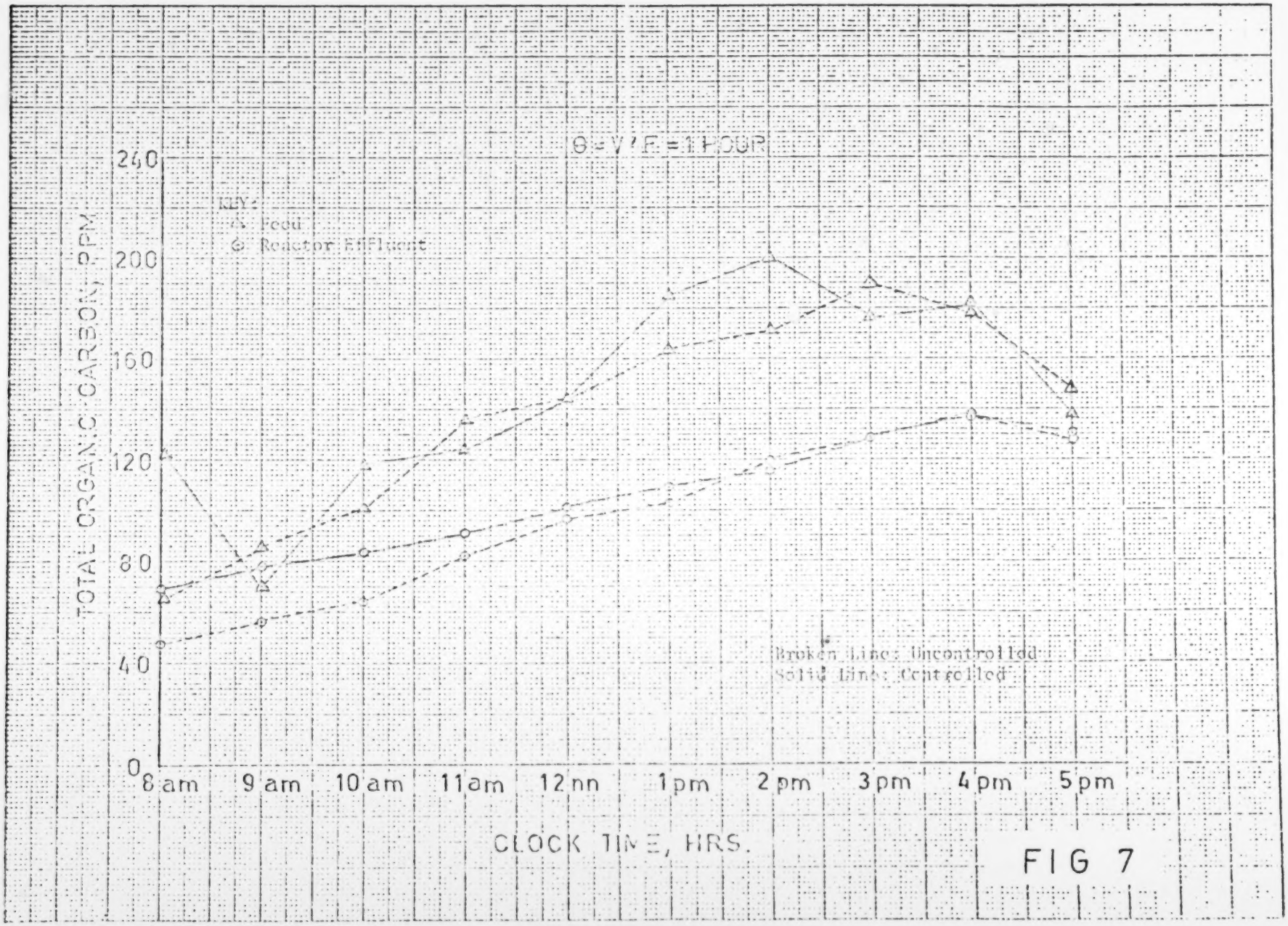

FIG 7

K&E 10 X 10 TO THE CENTIMETER 46 1510
10 X 25 CM.
KEUFFEL & ESSER CO.

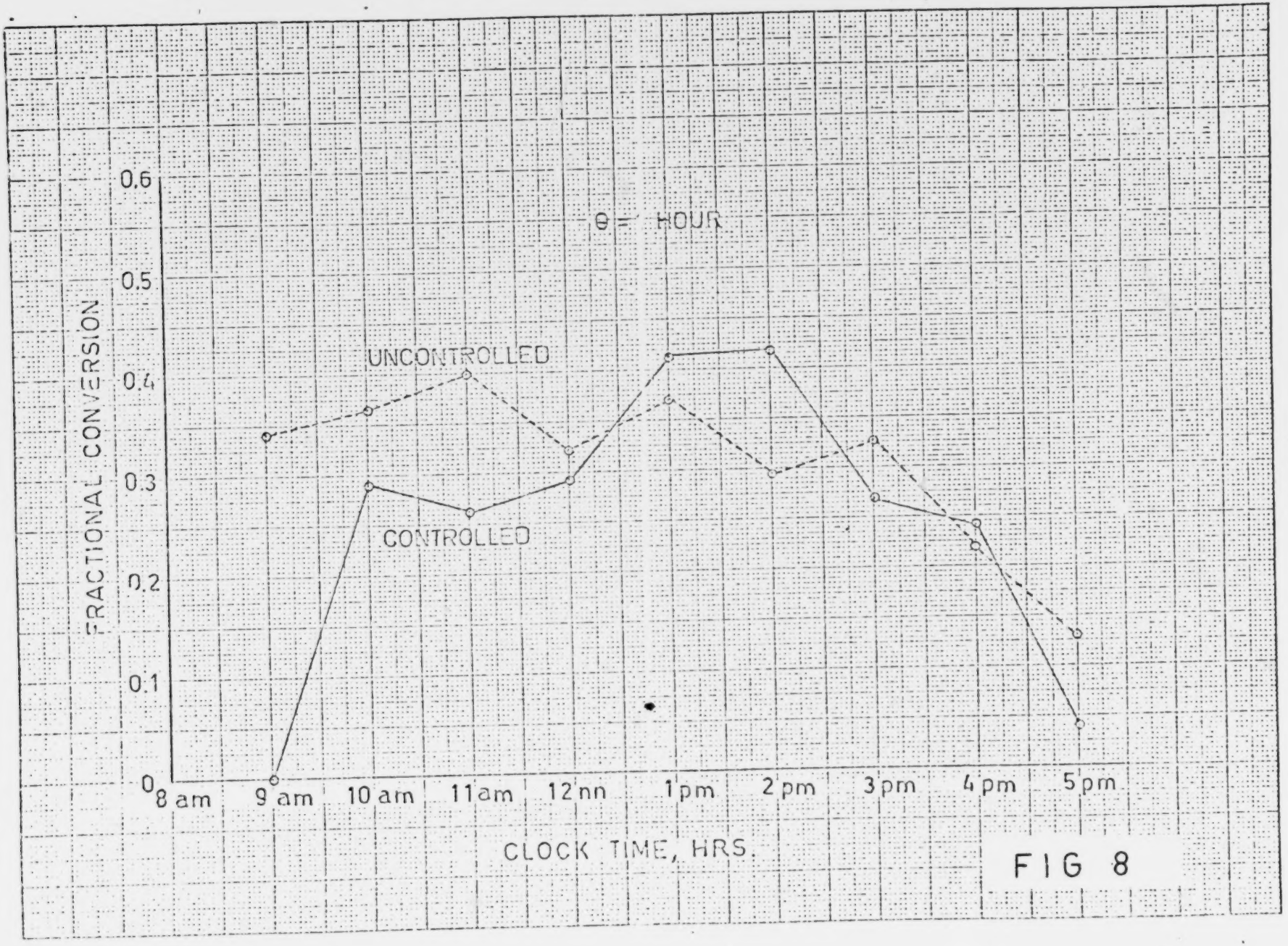

FIG 8

K&E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

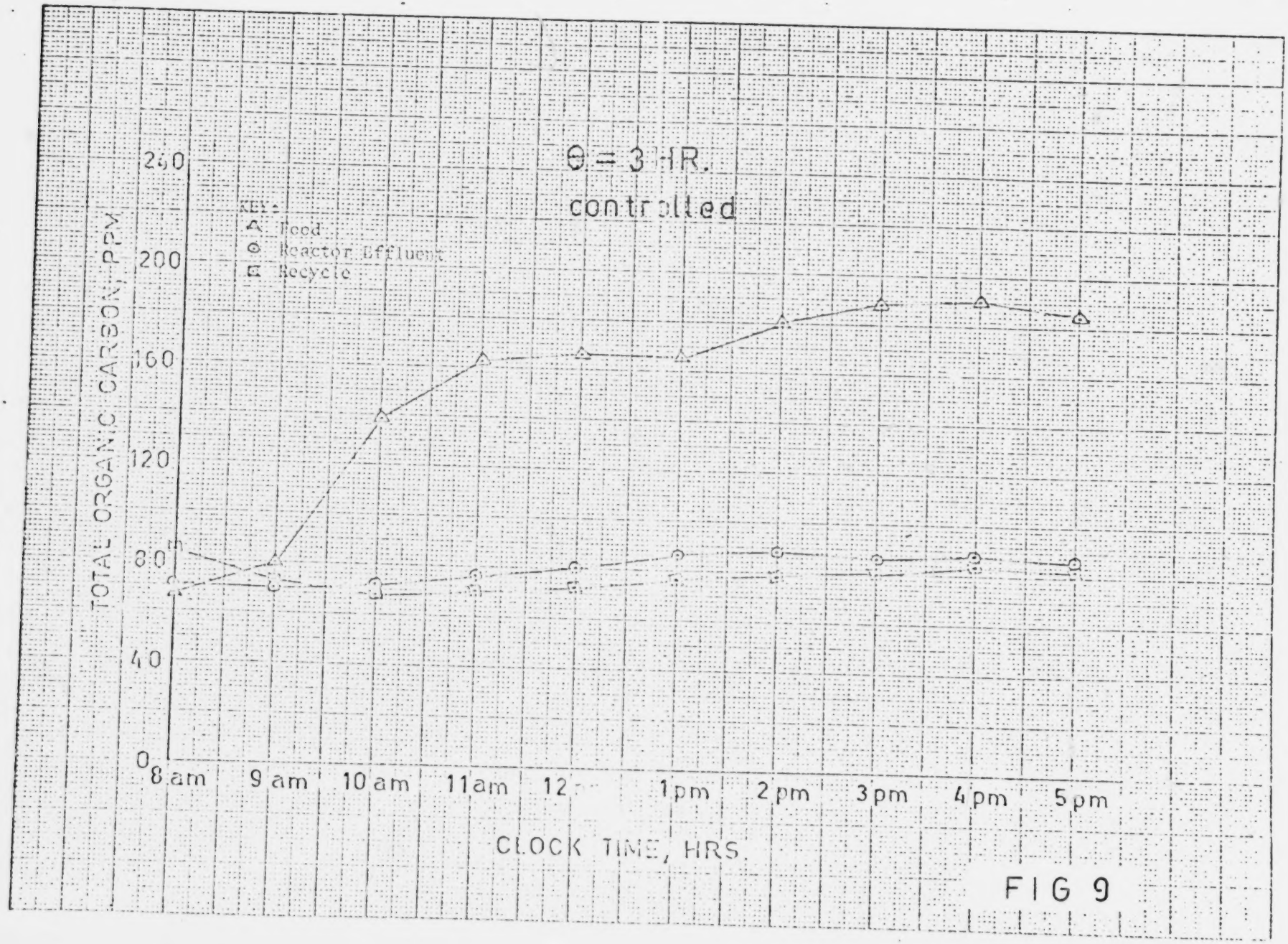

FIG 9

K&E 10 X 10 TO THE CENTIMETER 46 1510
10 X 25 CM.
REUFFEL & ESSER CO.

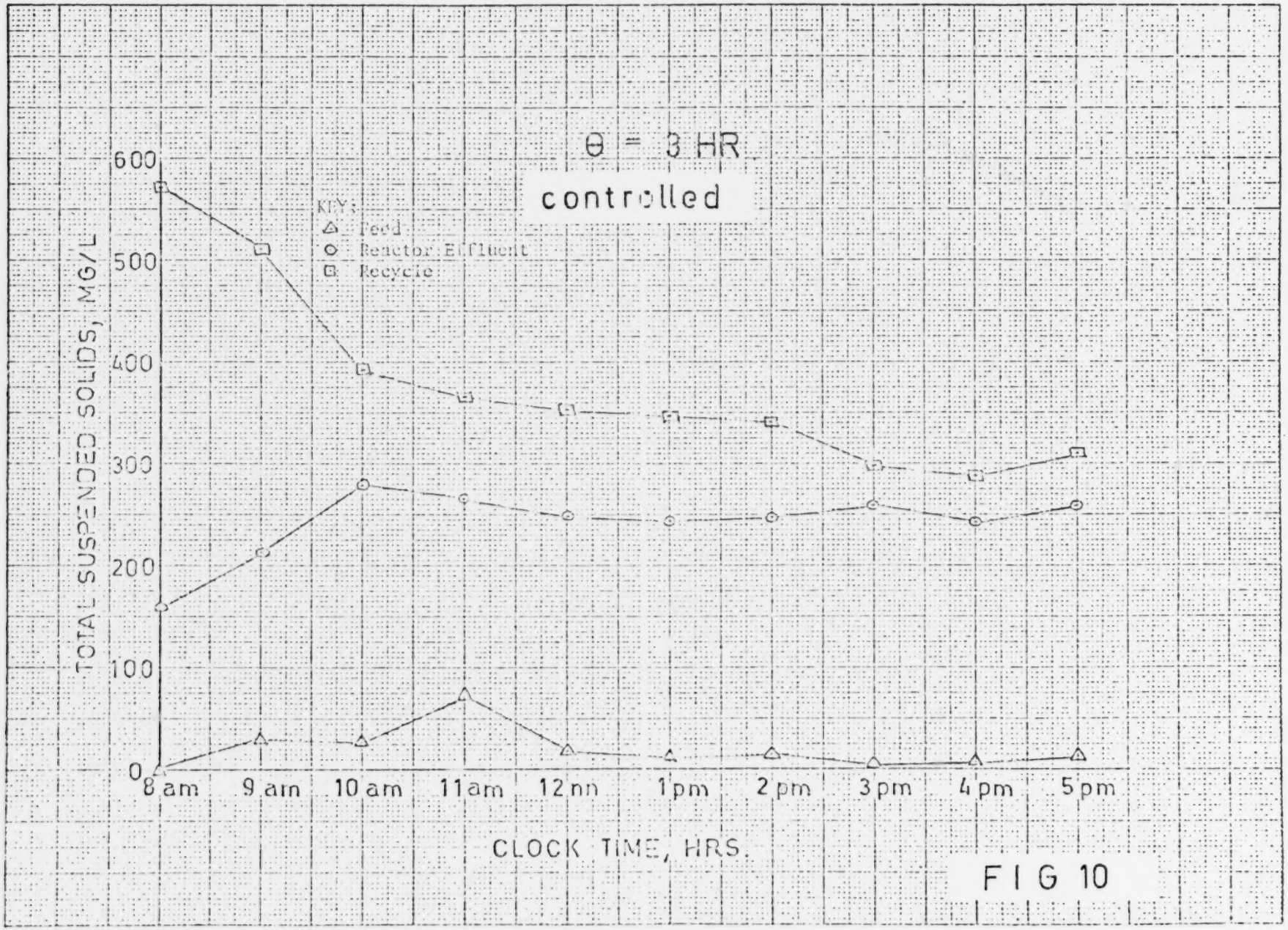

FIG 10

K&E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM.
MADE IN U.S.A.
KEUFFEL & ESSER CO.

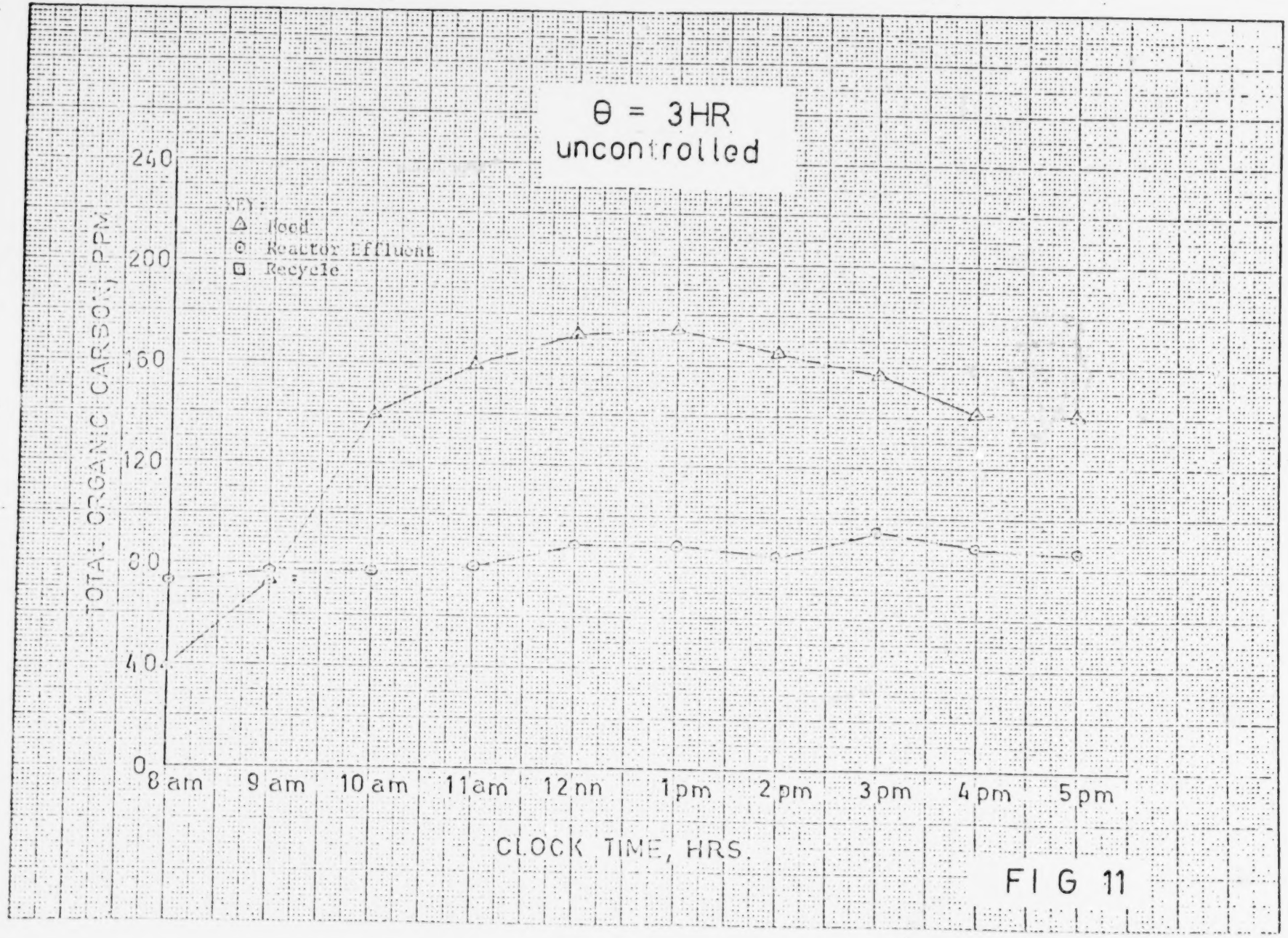

FIG 11

K&E 10 X 10 TO THE CENTIMETER 46 1510
19 X 25 CM.
KEUFFEL & ESSER CO.
MADE IN U.S.A.

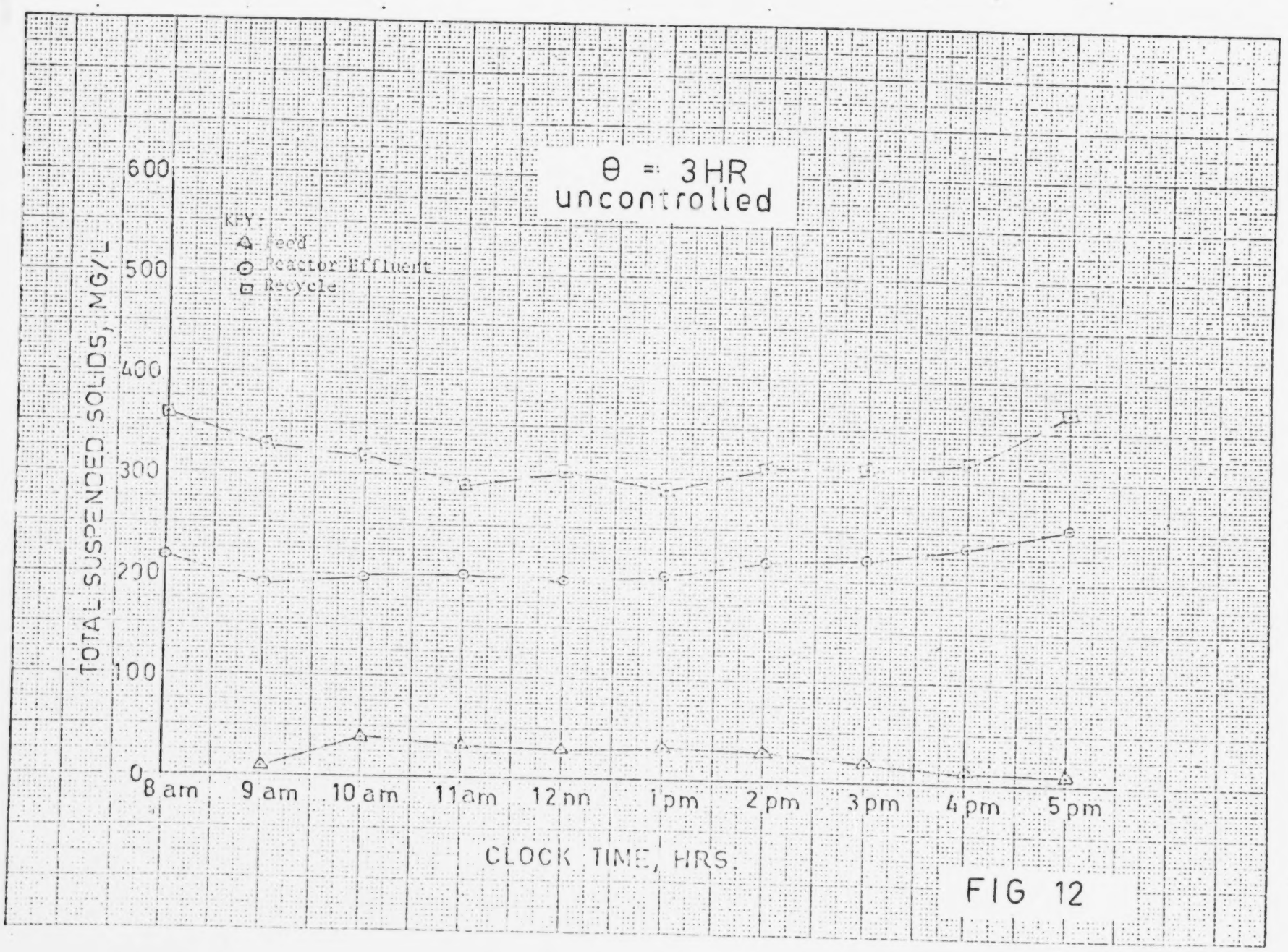

FIG 12

K&E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM.
KEUFFEL & ESSER CO.
MADE IN U.S.A.

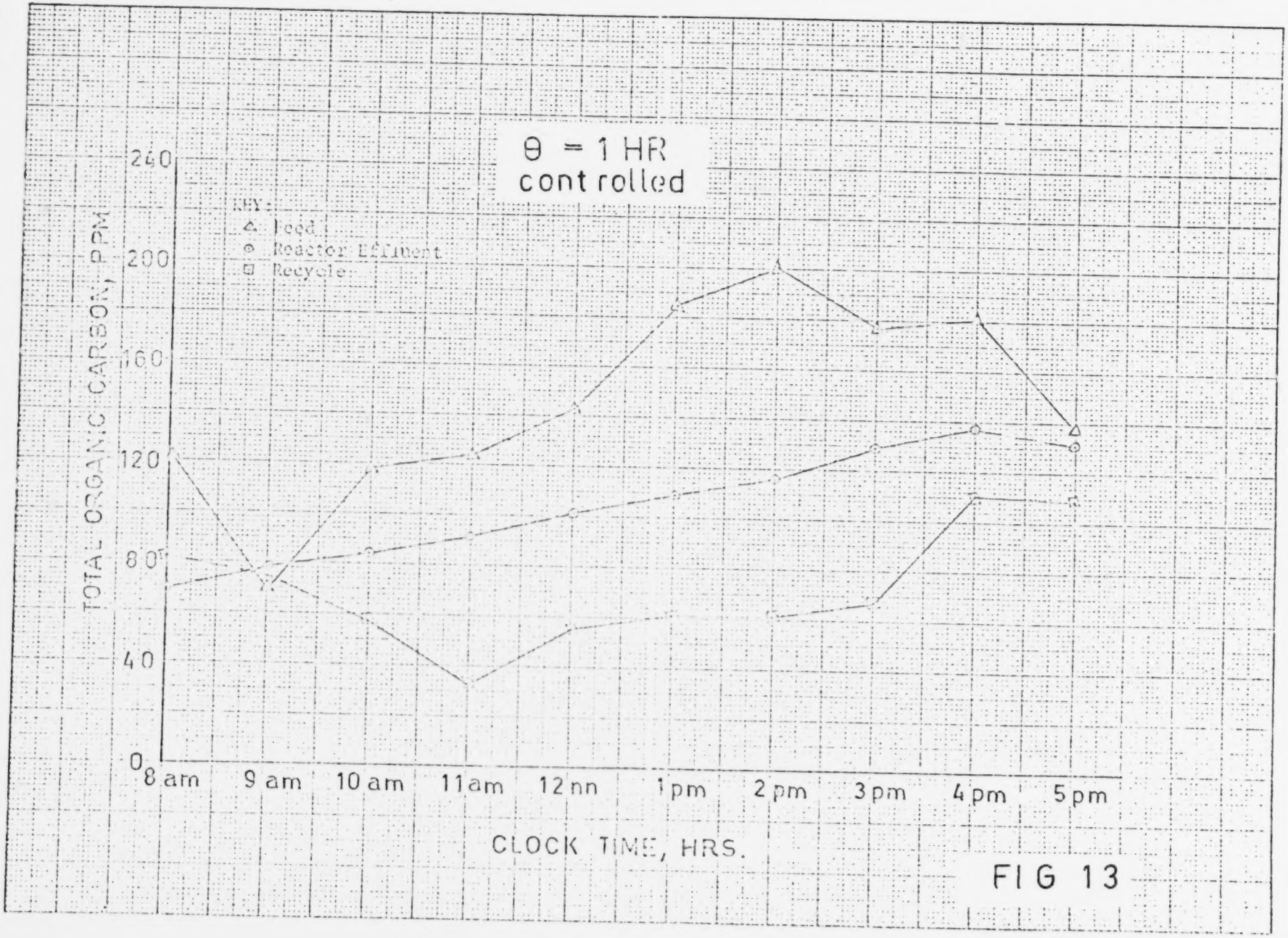

FIG 13

KEUFFEL & ESSER CO. 10 X 10 TO THE CENTIMETER 10 X 25 CM. 46 1510 MADE IN U.S.A.

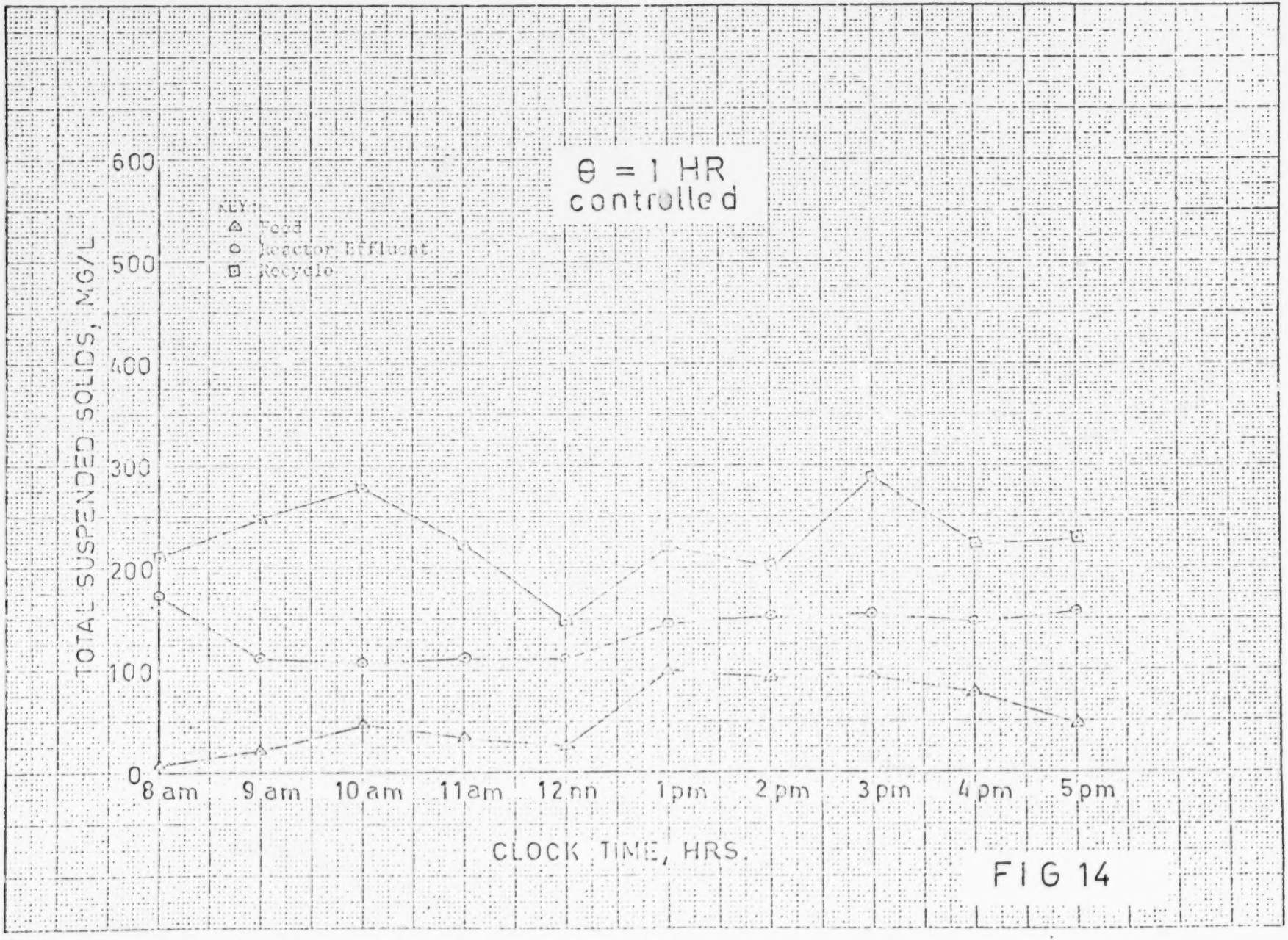

FIG 14

10 X 10 TO THE CENTIMETER 46 1510
10 X 25 CM.
KEUFFEL & ESSER CO.

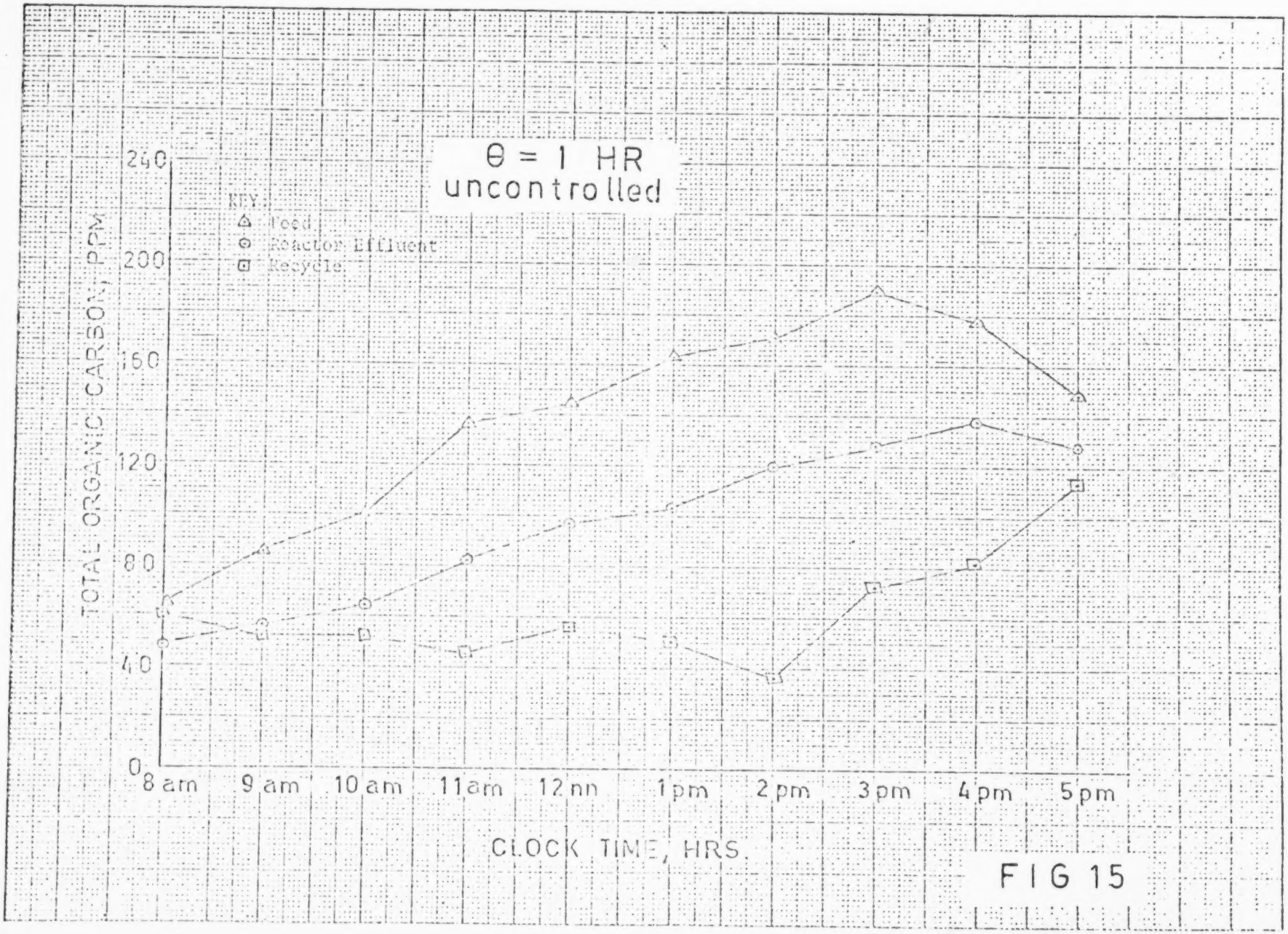

FIG 15

KEUFFEL & ESSER CO. MADE IN U.S.A.

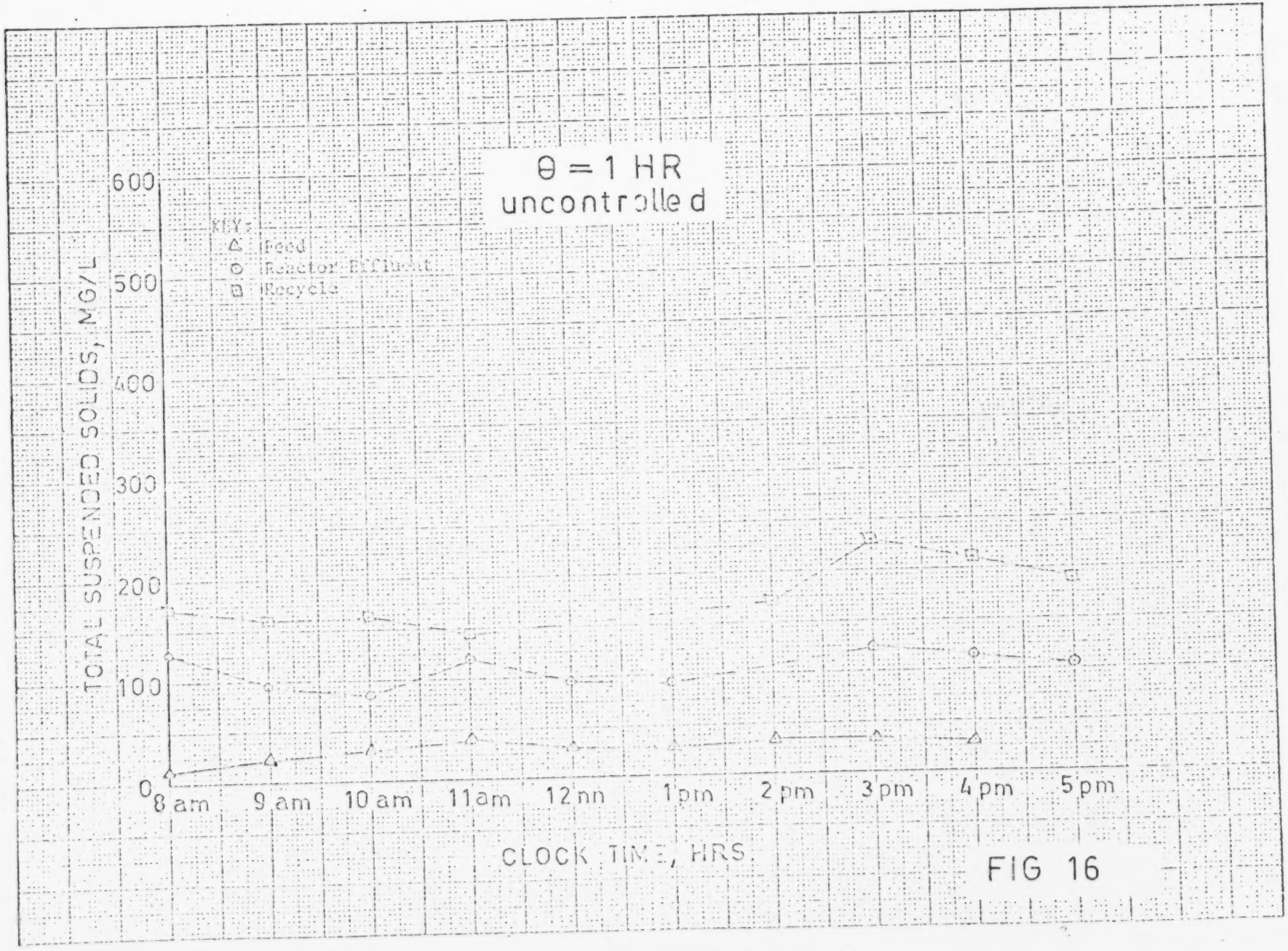

FIG 16